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# **THERMO-CHEMICAL ACTUATORS FOR EXOSKELETON APPLICATIONS**

**Phase I SBIR  
Sponsored by DARPA/DSO  
Contract No. DAAH01-00-C-R032**

**Presented at DARPA TIM/CHAP Kickoff  
26-28 June 2000**

**Presented by Dodd Stacy  
Creare Incorporated**



# Phase I SBIR Program

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## | Objective:

- Demonstrate the Technical Feasibility of Powering an Exoskeleton Load Carriage System with Thermo Chemical Actuators

## | Scope:

- Experiment  
Demonstrate Combustor
- Analysis  
Define Requirements/Size Components/Predict Performance
- Design  
Develop Package/Assess Mass, Volume



# Project Schedule

Tasks	Months							
	11/99	12/99	1/00	2/00	3/00	4/00	5/00	6/00
1. Develop Catalytic Combustor								
2. Develop Analytical Models								
3. Design TCA System								
4. Management and Report				♦PR				♦FR

# Program Participation

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- | **Contractor:**        **Creare Incorporated**  
                             **Hanover, New Hampshire**
- | **Objective:**         **Conduct Phase I SBIR Program**
- | **Status:**             **Program to be Completed 2 July 2000**



# Major Accomplishments, 6/99 - 6/00

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- | Technical Effort Has Been Completed
- | Technical Feasibility of Proposed Concept Has Been Demonstrated
- | Regenerator Matrix Fabrication Approach Has Been Proven



# Program Findings and Future

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- | **Thermo-Chemical Actuators (2) Can Power an Exoskeleton Load Carriage System of:**
  - 100 Kg Capacity, for
  - 24+ Hours (~100 Km) of March, on
  - One 0.5 Kg Hydrocarbon Fuel Canister (e.g. Propane),
  - 10 Kg or Less Total Mass (2 Actuators and Fuel)
- | **Phase I Results Support Transition to Phase II Demonstration of Powered Lower Body Exoskeleton**
- | **Phase II Demonstration Hardware Could Be Evaluated for Transition to Land Warrior Program, Others**



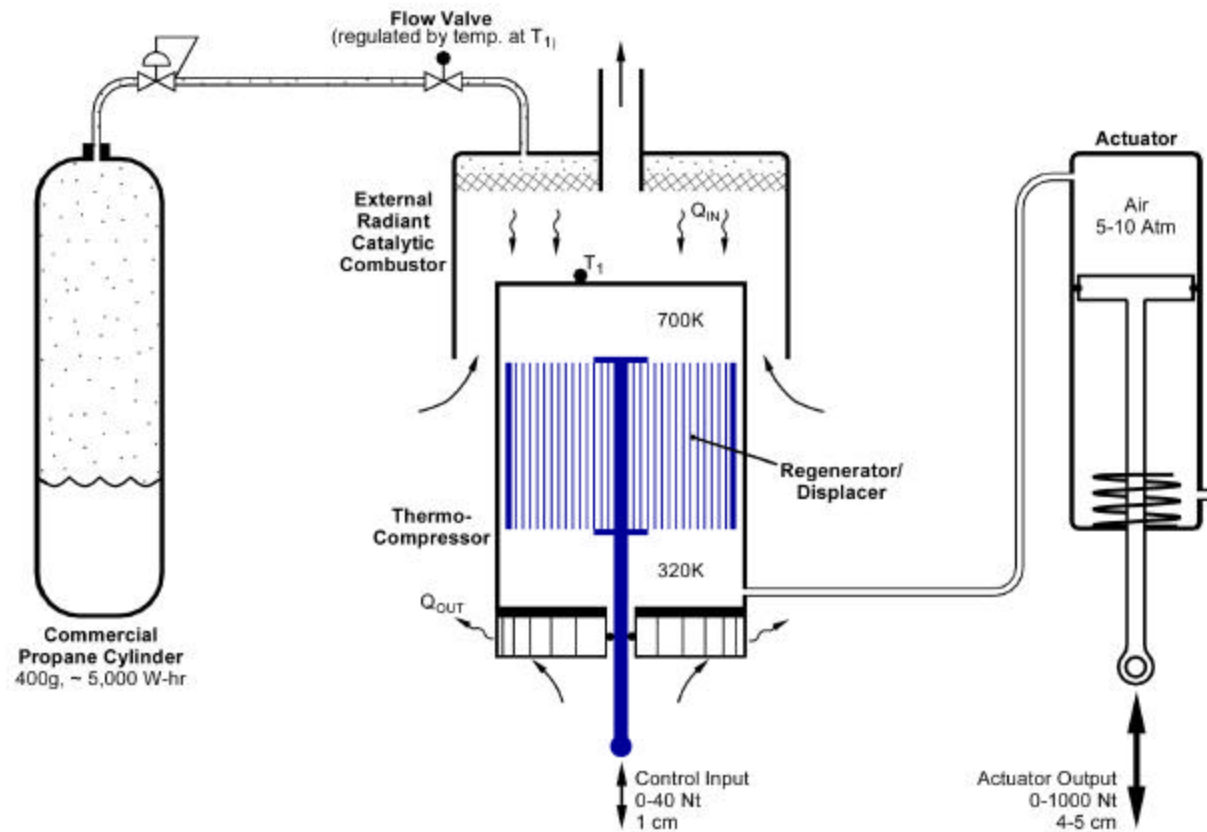
# Thermo-Chemical Actuator Description

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- | Regenerative “Hot Air” Engine Cycle
- | External Catalytic Combustion
  - Quiet
  - Simple, Low Bandwidth Fuel Control
  - Fuel Flexible
- | Cycles at Gait Cadence (2 Hz)
- | Linear Output, Demand-Controlled Stroke Amplitude
- | Generates 12-14 VDC Power for Internal Use, External Battery Charging



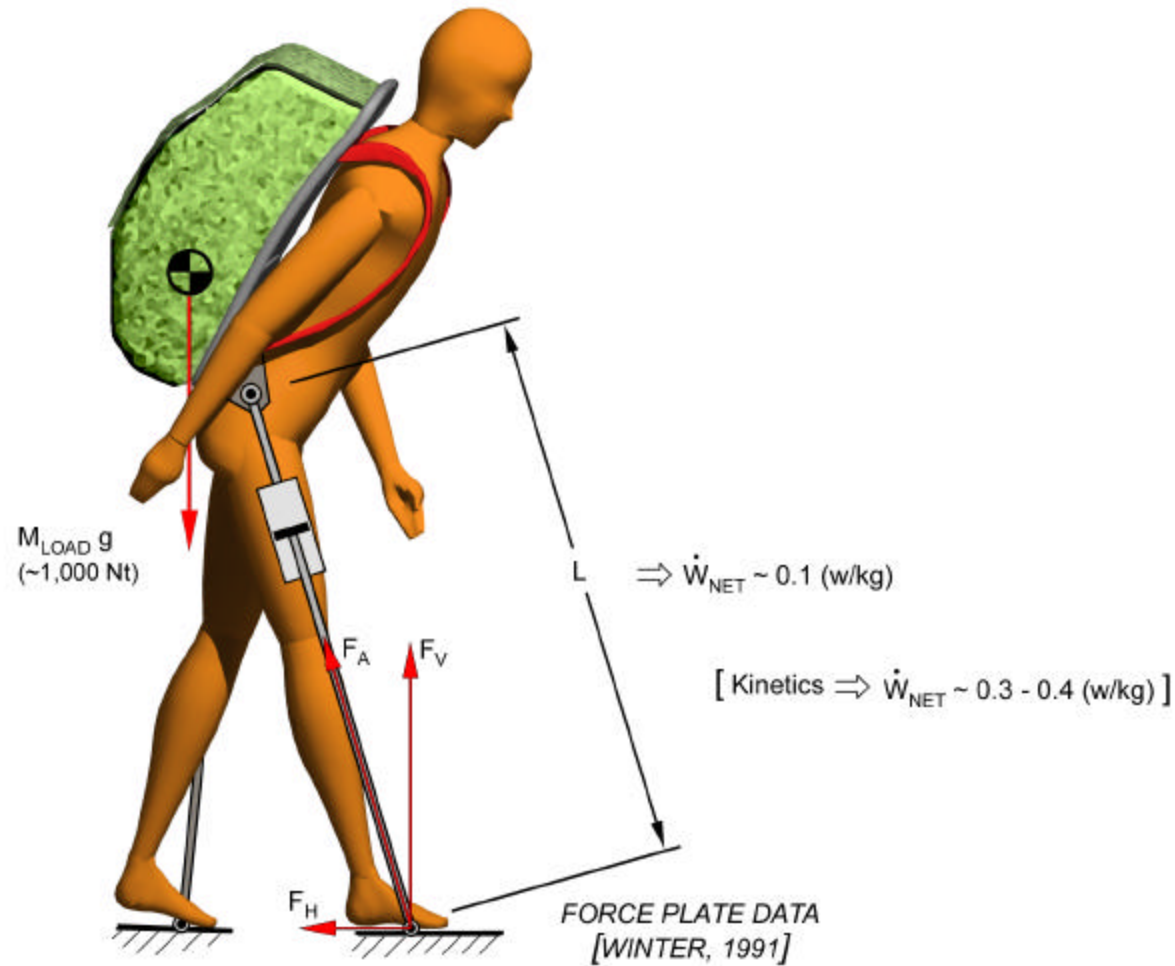
# TCA Schematic



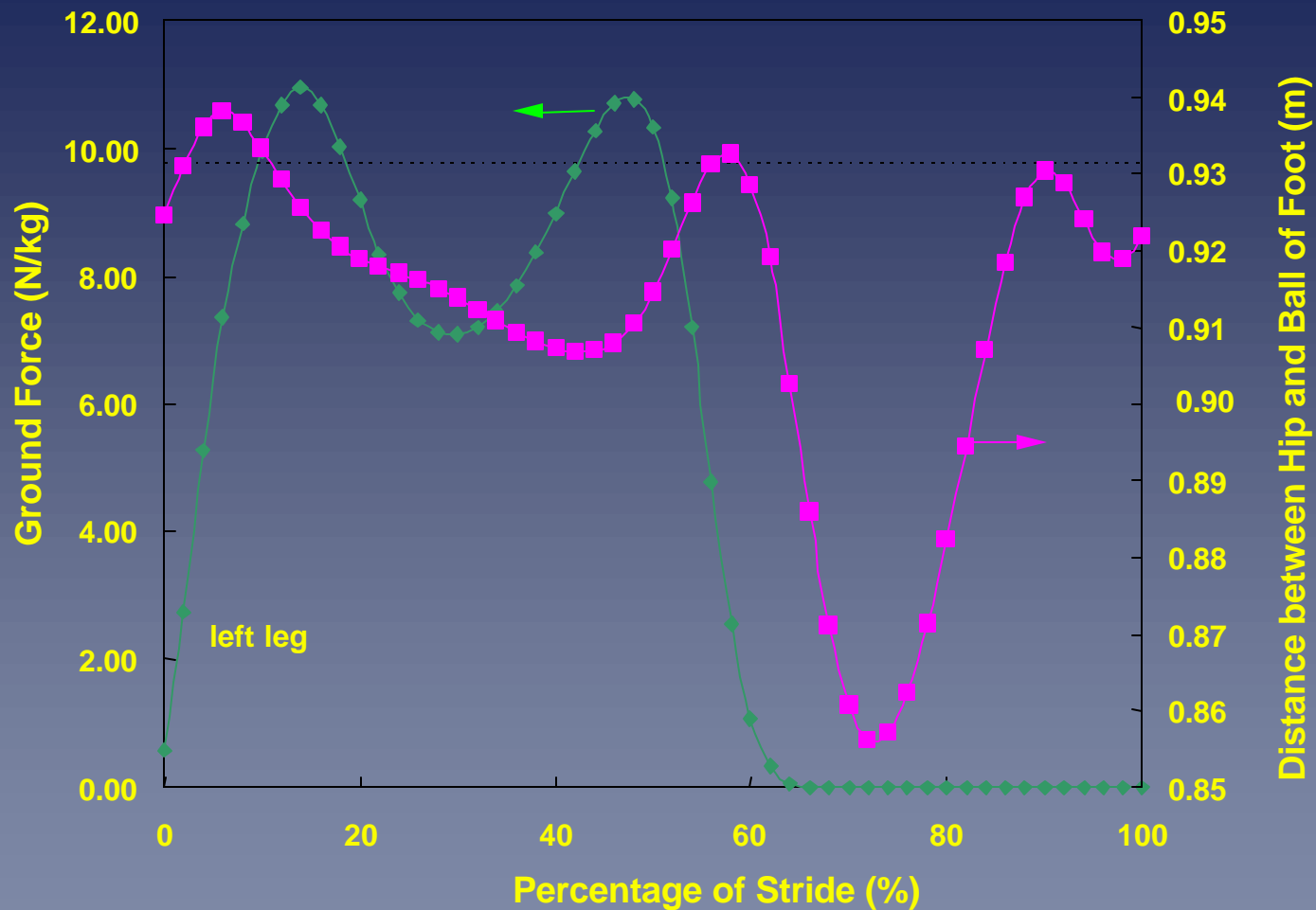
THERMO-CHEMICAL ACTUATOR SCHEMATIC



# Actuator Design Basis



# Actuator Design Basis (continued)



TCA Baseline Design Cycle of Force and Stroke

# TCA Control System

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- | **Objective: Vary TCA Mechanical Impedance Throughout Gait Cycle to Match the Impedance of the Operator's Leg**
- | **Algorithm: Combined Feedforward and Feedback Controllers, Adaptive Determination of Leg Impedance**
- | **Architecture:**
  - Inner Analog Loop to Control TCA Impedance
  - Outer Digital Loop to Determine TCA Impedance for Proper Overall Operation



# TCA Control System (continued)

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## | Sensors:

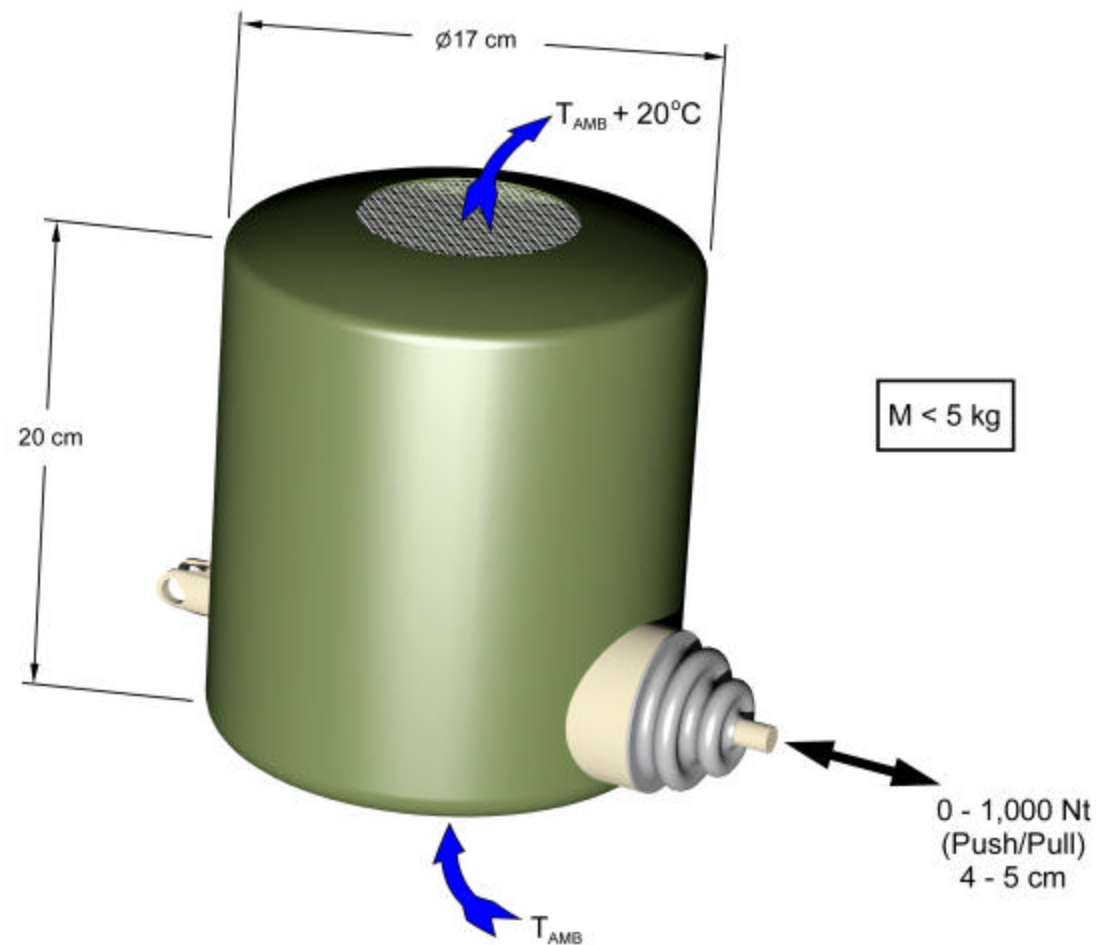
- Operator Foot Sole Pressure
- Position
- Pack Frame Shoulder Strap Tension

## | Bandwidth: 20-25 Hz, Limited by TCA Displacer Drive Motor Torque

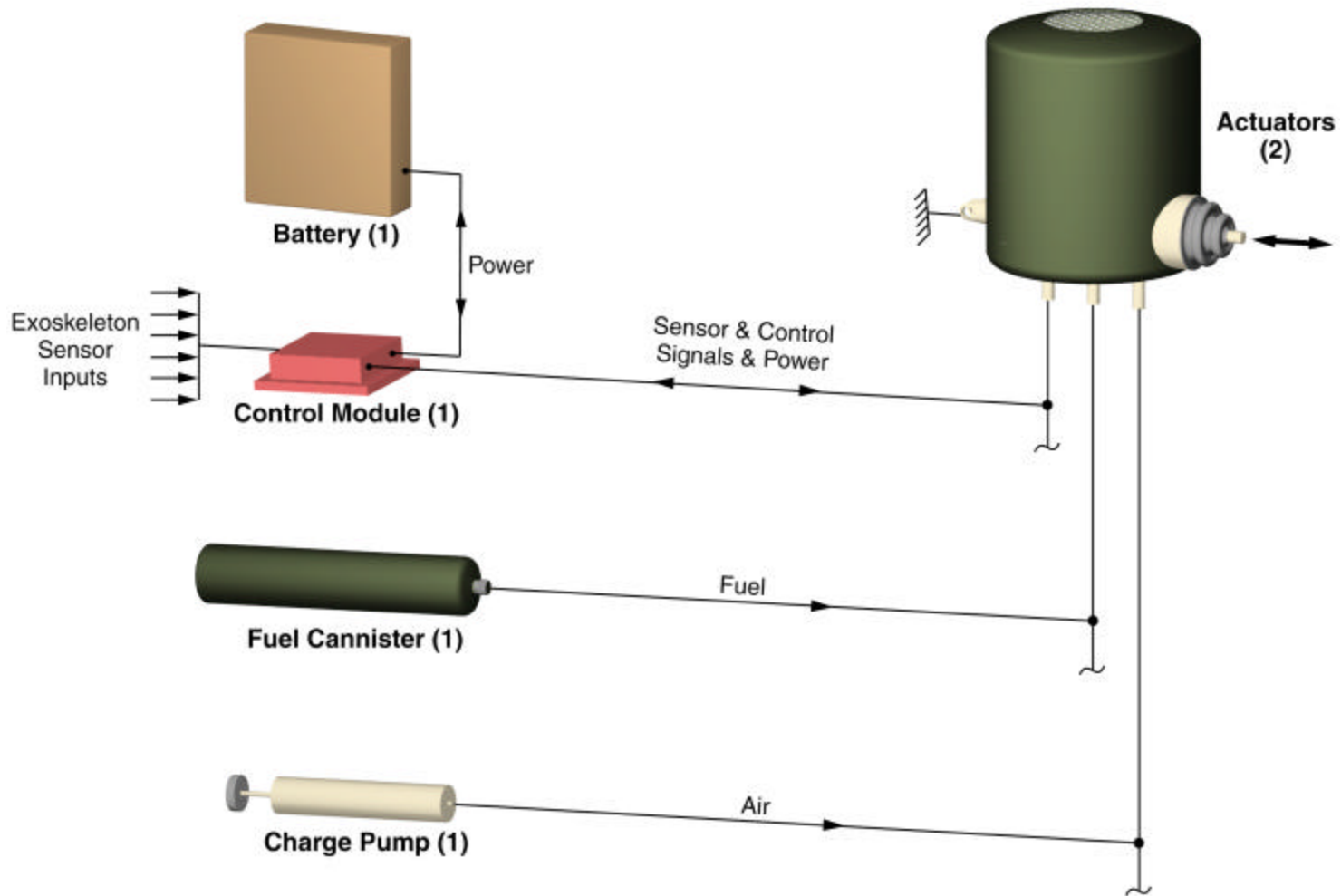


# Actuator Package - 100 Kg Capacity

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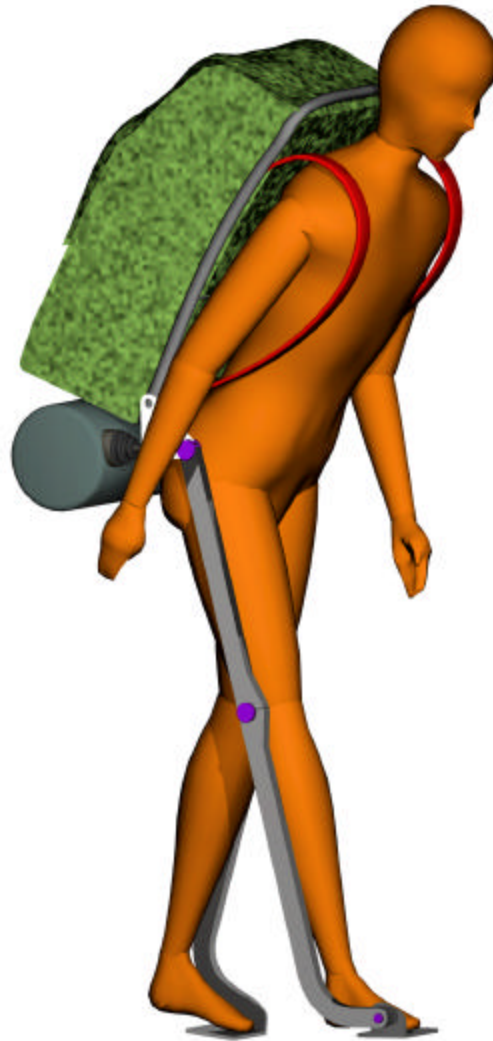


# TCA System Schematic

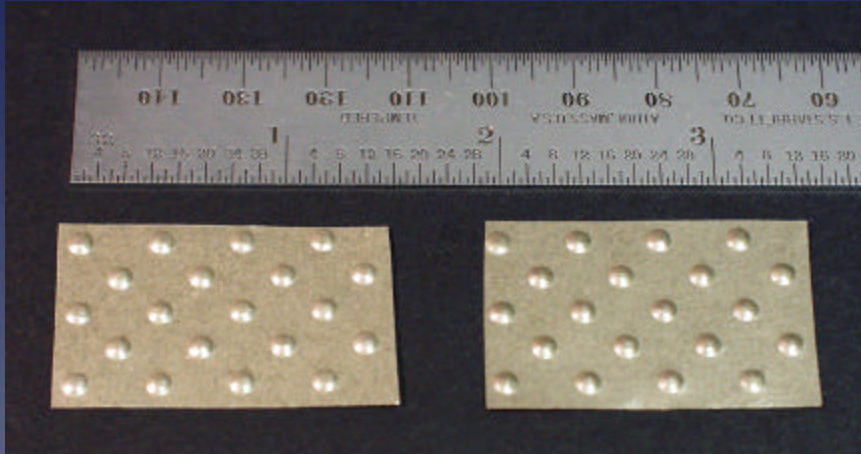


# Exoskeleton System Packaging Concept

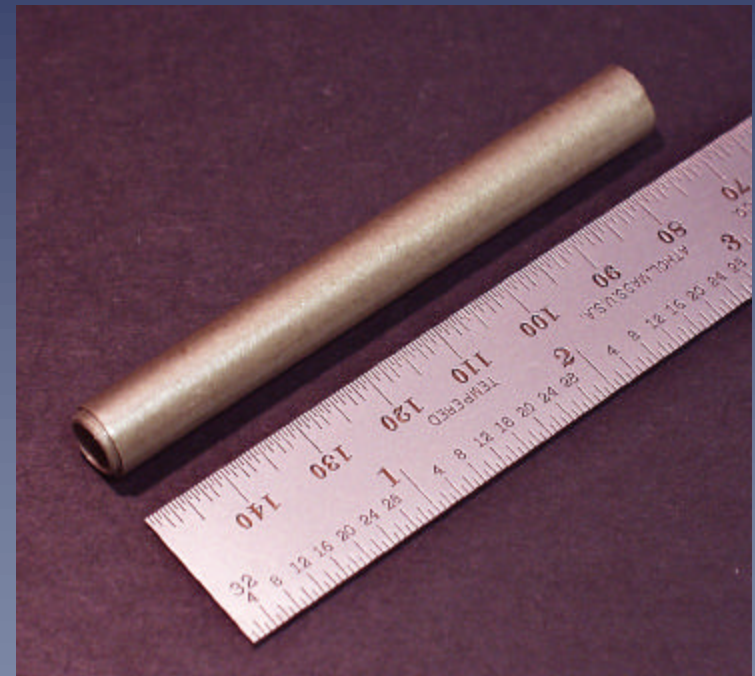
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# Regenerator Matrix Forming



Spacing Dimples in Cured 0.1 mm Micanite



Cured Matrix Sheet Coil



# TCA Fuel Consumption

